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**Proximal femoral canal shape is more accurately assessed
on AP hip radiographs than AP pelvis radiographs
in primary hip osteoarthritis**

Abstract

Purpose

The objectives of the present study were to determine (1) whether differences in the radiographic appearance of the proximal femoral canal exist on corresponding AP pelvis and AP hip radiographs, and (2) whether radiographic assessment of canal shape is accurate with reference to computed tomography (CT).

Methods

In a retrospective study, corresponding radiographs and CT scans of 100 consecutive patients with primary hip OA were evaluated. Active shape modelling (ASM) was performed to assess the variation in proximal femoral canal shape and to identify differences between AP hip and AP pelvis views. Differences in the medial cortical flare between radiographs and CT were quantified using least squares curve fitting.

Results

ASM identified significant differences in the assessment of canal shape on corresponding AP hip and AP pelvis views. Curve fitting demonstrated a good agreement between AP hip radiographs and CT. Agreement between AP pelvis radiographs and CT was less good.

Conclusions

In contrast to AP pelvis radiographs, AP hip radiographs allow a more accurate and reliable assessment of proximal femoral canal shape in the frontal plane in primary hip OA. Our findings may improve stem fit in total hip arthroplasty without the routine use of CT.

Introduction

Accurate preoperative templating is an essential requirement in contemporary total hip arthroplasty (THA) as it aids the surgeon in the selection of appropriate implant geometry and size, and suggests positioning of prosthetic components(1,2).

Unlike cemented femoral components, in which a geometrical mismatch between the femoral component and the medullary canal of the proximal femur is required for fixation, cementless femoral reconstruction aims for a close fit between the implant and the endosteal surface of the proximal femur(3,4). Stable primary fixation is achieved by press-fit implantation of a slightly oversized implant into the prepared medullary canal(5). Primary stability is essential to minimise micromotion at the implant bone interface and it allows secondary biological fixation of the implant (osteointegration)(6,7). A number of studies have highlighted the importance of metaphyseal stem fit to reduce micromotion at the implant bone interface(3,8), and to minimise stress-shielding(9,10). Despite promising long-term results of some cementless stems(11-14), an increased risk of aseptic loosening has been reported for undersized femoral components(15) and there is still is concern that progressive periprosthetic bone loss may compromise long-term stem performance(16). This is particularly important with regard to the rising number of THAs performed in young and active patients(17).

In preoperative templating for THA, anteroposterior (AP) pelvis radiographs are commonly used because they provide additional information regarding pelvic and contralateral hip anatomy, and allow assessment of leg length discrepancies(18). However, the appearance of canal shape on plain radiographs may be misleading as a result of inaccurate patient positioning and difficulty controlling femoral rotation(19,20). It has been previously

demonstrated that standardised AP hip radiographs allow a more accurate assessment of proximal femoral geometry (i.e. femoral offset) than AP pelvis views(21).

The objective of the present study was to investigate which radiographic view allows the most accurate assessment of the femoral canal in patients with primary hip OA. We aimed to determine (1) whether differences in the radiographic appearance of the proximal femoral canal exist between corresponding AP pelvis and AP hip radiographs, and (2) whether quantitative radiographic assessment of canal shape is accurate with reference to canal shape determined from computed tomography (CT).

Materials and Methods

Study Cohort

We retrospectively evaluated a consecutive series of 152 patients who had undergone cementless THA for primary end-stage hip osteoarthritis (OA) between July and December 2009. For preoperative templating, standardised AP pelvis radiographs, AP hip radiographs and CT scans of the affected hip were obtained, and all images were retrieved in generic DICOM format.

Patients with previous operations, secondary forms of OA or medication affecting bone metabolism were excluded from the present study. Patients in whom THA was performed bilaterally during the study period were only included with the first procedure side. Fifty-two patients were excluded according to the criteria stated above, leaving 100 patients (43 males, 57 females, mean age 61 (range: 45-74) years, mean body-mass-index (BMI) 27.5 (range: 20-45) kg/m², Table 1) that were included in the present study. In all cases, the diagnosis leading to THA was primary OA. The study was approved by the institutional review board.

Radiographic Protocol

For all patients, low-centered AP pelvis radiographs and AP hip radiographs were taken in supine position according to a standardised radiographic protocol to achieve reproducible projection. To correct for effects of magnification, a metal calibration sphere of 25 mm diameter was positioned on the inner thigh at the anterior-posterior level of the femoral head.

For AP pelvis radiographs, both legs were symmetrically internally rotated by 15 degrees using a leg retainer. The crosshairs of the beam were centred on the pubic symphysis.

For AP hip radiographs, the crosshairs of the beam were directed to the midpoint between the anterior superior iliac spine and the symphysis to centre the beam on the centre of the femoral

head of the diseased hip. The affected leg was internally rotated and retained so that the greatest prominence of the greater trochanter was palpated at its most lateral position to bring the femoral neck into the coronal plane(22). When internal rotation of the leg was not sufficient due to external rotation contracture, the affected hip was additionally elevated on the AP hip view using a wedge.

During the study period, two x-ray tubes were in use: Canon CXDI series [Canon Inc., Tokyo, Japan] and Philips Bucky Diagnost VE VT [Royal Philips Electronics Inc., Amsterdam, Netherlands]. The tube-to-film distance was 1150 mm, with the tube orientation perpendicular to the table.

CT Protocol

For the CT scans, patients were positioned supine, with legs retained in neutral rotation, which was confirmed by scout views. The scans were obtained in two sets: from the cranial aspect of the acetabulum to below the lesser trochanter (4 mm slice spacing), from below the lesser trochanter to 50 mm distally of the femoral isthmus (8 mm slice spacing). All hip CT scans were performed using a Toshiba Aquilion 16 CT scanner [Toshiba Corp., Tokyo, Japan] with gantry tilt 0, 120 kV and a field of view (FOV) of 250 mm.

Active Shape Modelling

The present study used Active shape modelling (ASM), which is a statistical method to describe variation in shape, to identify differences in proximal femoral canal shape on corresponding AP hip and AP pelvis radiographs. The model was built using an ASM tool kit (Manchester University, Manchester, UK)(23).

To define the shape of the proximal femoral canal, the ASM template used in this study contained 33 points from a 67-point model of the proximal femur (Figure 1). Key points were

placed at reliably identifiable features of the endosteal cortices (e.g. at the femoral isthmus, the lesser trochanter, the head neck junction), while the remaining points were spaced approximately evenly between features. Each key point was placed on the same feature on corresponding images to allow comparison between shapes and to perform point-based measurements.

ASM works by calculating distances of an individual set of landmark points that define the outline of an object of interest from the mean position of equivalent points in a set of images. Procrustes analysis(23) is performed to align all objects as closely as possible to ensure that differences in point placement are genuinely due to variation in shape, rather than in size, position or rotation of the object. Thereafter, principal component analysis (PCA)(23), a dimension reduction technique, is used to generate modes of variation that describe the variation of shape in the given dataset. In ASM, shape is described by a series of orthogonal modes of variation. Each mode is orthogonal to all the others, and hence, each mode is an independent descriptor of shape. For each mode in the model, mean and SD values for the entire dataset of corresponding AP pelvis and AP hip radiographs were calculated, and the mean value of each mode was scaled to zero. Mode scores for each radiograph were calculated and expressed in terms of how many standard deviations it lay from the mean value (zero) of that mode.

Curve fitting

For comparison of the medial cortical flare between corresponding radiographs and CT, points on the endosteal surface were depicted as scatter plots (x: femoral shaft axis (FSA), y: perpendicular distance from FSA). We performed a least square curve fitting ($f(x) = ax^b + c$) to quantify differences on corresponding modes of imaging.

On radiographs, endosteal dimensions were derived from the ASM template and scaled with reference to the calibration marker. The femoral shaft axis was defined as the best fit line between the midpoints of the endosteal surface from a point 100 mm below the lesser trochanter to the midpoint at the lower aspect of the lesser trochanter.

On corresponding CT scans, measurements of endosteal dimensions were performed using a validated MATLAB [version 7.10, The MathWorks Inc., MA, USA] programme. The programme enabled the user to select points from pre-selected axial CT slices and performed vector calculations in the 3D coordinate system of the CT scanner. Six slices were selected: S1 (head neck junction), S2 (centroid), S3 (proximal aspect of lesser trochanter), S4 (mid lesser trochanter), S5 (distal lesser trochanter), S6 (isthmus). The endosteal dimensions of the femoral canal were determined on each slice with a best-fit ellipse. Endosteal distances were calculated in the plane of the femoral neck axis which was defined according to the single slice method described by Sugano(24), and perpendicular to the femoral shaft axis which was defined as the line between the centre of the femoral canal at the isthmus (S6) and at the lower aspect of the lesser trochanter (S5).

Measurement reliability

For CT measurements, intra- and inter-observer reliabilities for determining canal diameters and the femoral neck axis were evaluated for 15 randomly selected patients by two independent observers using single-measure intra-class-correlation coefficients (ICC) with a two-way-random effects model for absolute agreement.

For placement of keypoints on the ASM template, the mean error was determined for 2 independent observers.

Statistical analysis

In order to investigate differences in endosteal shape of the proximal femur between corresponding AP pelvis and AP hip radiographs, differences in normalised mode scores were tested for the first 10 modes using paired-samples t-tests. Results with $p < 0.05$ were considered as significant, $p < 0.001$ as highly significant.

Coefficients of curve fits were calculated with 95% confidence intervals (95%CI), and goodness of curve fit was determined using R^2 values.

Statistical analysis was carried out using PASW Statistics 18 [SPSS Inc. an IBM company, IL, USA] and MATLAB [version 7.10, The MathWorks Inc., MA, USA].

Results

Measurement reliability

For repeated CT measurements performed on 15 datasets, intra-observer ICCs ranged from 0.93-0.99, inter-observer ICC from 0.87-0.99, respectively.

The mean error for placement of keypoints on the radiographic ASM template (n=15 datasets) was <1 mm for both intra- and inter-observer measurements.

ASM

PCA identified 10 independent shape modes that accounted for 96% of the overall variation in the endosteal shape of the proximal femur. Mode scores for AP pelvis radiographs showed a higher scatter compared to those derived from AP hip views. For 7 out of 10 modes, significant differences in distribution of mode scores between corresponding AP hip and AP pelvis views were observed ($p < 0.010$, Table 2). The greatest variability of canal shape occurred on the medial femoral cortex between the lesser trochanter and the head-neck junction. Modes 4 and 5 identified significant differences in the medial cortical flare ($p < 0.001$) between corresponding AP pelvis and AP hip radiographs (Figure 2).

Comparing the recovered average shapes of corresponding radiographs, the flare of the medial femoral cortex was underestimated on AP pelvis views with the calcar and neck region appearing in valgus orientation. On AP hip views, the medial cortical flare was more distinct and appeared in more varus orientation (Figure 3).

Curve fitting

The derived least square curve fits of the medial cortex demonstrated a good agreement between AP hip radiographs and CT. Agreement of the curve fit coefficients between AP pelvis radiographs and CT was less good (Figure 3, Table 2).

Discussion

In cementless THA, the endosteal fit of the femoral component is a major factor determining load transfer and, consequently, periprosthetic bone remodelling. Accurate metaphyseal stem fit is essential to reduce micromotion at the implant bone interface(3,8), and to minimise stress-shielding(9,10). It has been shown that femoral fit predicts not only radiographic changes following THA(9,10), but also affects clinical results in terms of postoperative pain(25) and implant survival(15).

Therefore, accurate and reliable pre-operative templating is essential. Although standardised recommendations of patient positioning during radiography with 15 degrees of internal rotation of the lower limbs have been made(26) to ensure reproducible projection with the femoral neck in the coronal plane, several studies have demonstrated that radiographic assessment of femoral canal shape and geometry has limited reliability(27,28). CT is considered as the gold standard as it represents the 3D shape and geometry of the proximal femur, and thus allows a more accurate selection of the implant and its position(28).

The present study demonstrates that the endosteal shape of the proximal femoral canal varies considerably between individuals, and also in appearance between corresponding AP pelvis and AP hip radiographs. The greatest variation in femoral shape was observed in the proximal femoral metaphysis, predominately in the flare of the medial cortex.

On corresponding AP pelvis and AP hip radiographs, ASM identified significant differences in the flare of the proximal medial cortex, further indicating that the scatter of femoral canal flare was smaller and thus more reliably measured on AP hip radiographs.

Comparing the medial cortical flare as measured on radiographs to corresponding CT scans, AP hip radiographs were more accurate than AP pelvis radiographs as shown by the provided

curve fit equations. These findings may be explained by a better control of femoral rotation and the ability to compensate for external rotation contractures during positioning.

We acknowledge the following limitations of the present study:

Firstly, the target population were patients with primary end-stage hip OA. Care should be taken, therefore, when applying the present results to patients with secondary forms of OA, i.e. advanced deformity. However, for patients with primary OA, the present cohort can be considered as representative with regard to patient demographics. This limitation should be put into perspective as the leading diagnosis for THA is primary OA(29).

Secondly, we cannot retrospectively identify patients whose affected hip was elevated by 15 degrees on AP hip radiographs. Elevation appears to be beneficial in order to bring the femoral neck into the coronal plane and to minimise the adverse effect of external rotation contractures on radiographic projection. Recently, a study has highlighted the clinical relevance of palpating the lesser trochanter to assess femoral neck version(22).

Lastly, the present study used active shape modelling (ASM) to assess the overall variation and differences in the appearance of the proximal femoral canal on corresponding AP pelvis and AP hip radiographs. This method enables measurement of the variation in a complex shape, such as the hip(30,31). In ASM, a mode does not just capture one aspect of variation in femoral canal shape, it is a combination of evident and/or subtle differences between femurs(32). It can be difficult, therefore, to visually describe what aspect of shape variation each mode represents. However, at the same time this method is powerful and able to detect differences that are not necessarily evident with conventional radiographic measures (e.g. angles, distances or canal flare indices)(23).

Cadaver, radiographic and CT based studies have demonstrated that the anatomy of the femoral medullary canal is highly variable(33-35) and, as a consequence, a great variety of

cementless femoral stem designs and implant systems with different geometries, surface treatments and underlying principles of fixation are currently in clinical use. The growing popularity of bone preserving and minimally invasive procedures(36) has led to the development of novel “short” stem designs which aim for metaphyseal fixation and preservation of the femoral neck(37). Moreover, implants with multiple shape options have been introduced to account for individual patient anatomy(38,39). For these components, the intraoperative selection of the broach that provides the best fit is essential, but intraoperative assessment of endosteal cortical contact is difficult and can only be done radiographically with the broach *in situ*. Consequently, the surgeon has to make decisions prior to and during femoral canal preparation and needs to choose the broach that allows adequate fit with regard to individual patient anatomy. For third generation stems, preoperative templating of resection levels and implant fit may thus be even more critical than for straight tapered stems, since small inaccuracies in the preoperative assessment of canal shape may compromise proximal fixation and/or restoration of physiologic joint mechanics. Moreover, a mismatch of bone and implant shape may increase the risk for intraoperative periprosthetic fractures(40,41). Therefore, the present findings of differences in femoral canal shape between corresponding radiographs are of clinical relevance.

To our knowledge, this is the first study that demonstrates the reliability and accuracy in the assessment of proximal femoral canal shape on plain radiographs in patients with primary hip OA. We do not question CT as the gold standard in the assessment of proximal femoral geometry and shape and the provided radiographic protocol for AP hip views does not entirely account for potential measurement imprecision. Yet, AP hip radiographs reduce radiation exposure compared to CT and are an available and cost-effective method which may improve preoperative templating of stem fit.

In conclusion, AP hip radiographs allow a more accurate and more reliable assessment of canal shape than AP pelvis radiographs compared to CT. Although the ultimate decision of implant design, size and position must still be made intraoperatively, we recommend to routinely obtain AP hip radiographs for preoperative assessment of femoral canal shape in patients with primary OA. Our findings should assist surgeons in preoperative templating and may improve stem fit and restoration of joint geometry without the routine use of CT.

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Tables

	Entire cohort (n=100)	Males (n= 43)	Females (n= 57)
Age (years)	60.8 (45-74) (95%CI: 59.4-62.2)	61.0 (45-72) (95% CI: 58.7-63.3)	60.7 (45-74) (95%CI: 58.8-62.6)
Weight (kg)	79.7 (48.0-125.0) (95%CI: 76.6-82.9)	87.0 (60.0-125.0) (95% CI: 82.2-91.9)	74.2 (48.0-120.0) (95%CI:70.6-77.7)
Height (meters)	1.70 (1.53-1.91) (95%CI: 1.68-1.72)	1.77 (1.60-1.91) (95% CI: 1.75-1.79)	1.65 (1.53-1.76) (95%CI: 1.63-1.66)
BMI (kg/m²)	27.5 (20.3-44.6) (95%CI: 26.6-28.4)	27.7 (20.3-42.2) (95% CI: 26.3-29.1)	27.3 (20.5-44.6) (95%CI: 26.1-28.5)

Table 1

Demographic data of the entire cohort, male and female patients with range and 95% confidence intervals (95%CI).

	Mean Difference	95% CI		p-value
		Lower	Upper	
Mode 1	-0.896	-1.1037	-0.6875	< 0.001
Mode 2	0.096	-0.1357	0.3270	0.414
Mode 3	-0.943	-1.1643	-0.7225	< 0.001
Mode 4	0.485	0.3222	0.6482	< 0.001
Mode 5	0.346	0.1604	0.5328	< 0.001
Mode 6	-0.232	-0.5041	0.0404	0.094
Mode 7	-0.532	-0.7735	-0.2897	< 0.001
Mode 8	0.216	-0.0044	0.4381	0.055
Mode 9	-0.380	-0.6563	-0.1041	0.007
Mode 10	-0.344	-0.6031	-0.0855	0.010

Table 2

Results of paired T-tests showing differences in mode scores for corresponding AP hip and AP pelvis radiographs, with standard deviation (SD) and 95% confidence intervals (95%CI).

f(x) = ax^b+c	A	b	c	R²
AP pelvis (95%CI)	1.98 *10 ⁻⁹ (-7.953*10 ⁻¹⁰ -4.756*10 ⁻⁹)	4.458 (4.193-4.722)	4.349 (3.620-5.078)	0.811
AP hip (95%CI)	2.788*10 ⁻¹¹ (-4.62*10 ⁻¹² -6.038*10 ⁻¹¹)	5.3 (5.079-5.522)	5.62 (5.157-6.084)	0.904
CT (95%CI)	1.264*10 ⁻¹¹ (-9.747*10 ⁻¹² -3.503*10 ⁻¹¹)	5.455 (5.119-5.791)	5.794 (4.987-6.602)	0.879

Table 3

Least squares fit curve equations for the medial cortical flare on corresponding radiographs and CT with 95% confidence intervals (95%CI).

Figure Legends

Figure 1

ASM template:

The shape of the proximal femoral canal is described by 33 points placed on the endosteal surface of the medial and lateral cortex.

Figure 2

Overlay image of shape modes 4 (left) and 5 (right). The medial cortical flare shows greater variation than the lateral cortical flare. Mode scores for corresponding AP pelvis and AP hip radiographs were significantly different for both modes ($p < 0.001$, Table 2). The solid line represents the mean shape, the dashed lines represent ± 2 SDs.

Figure 3

Scatter plot with least square fits for the endosteal flare of the medial femoral cortex. The femoral shaft axis is aligned to the x-axis ($y=0$). The lesser trochanter is located at $x=150$ mm. The distance of points on the endosteal surface of the medial cortex with reference to the femoral shaft axis is plotted on the y axis (mm). Lines represent the least square fit ($f(x) = ax^b + c$) with 95% confidence intervals for corresponding AP pelvis radiographs, AP hip radiographs and CT.

Figure 1
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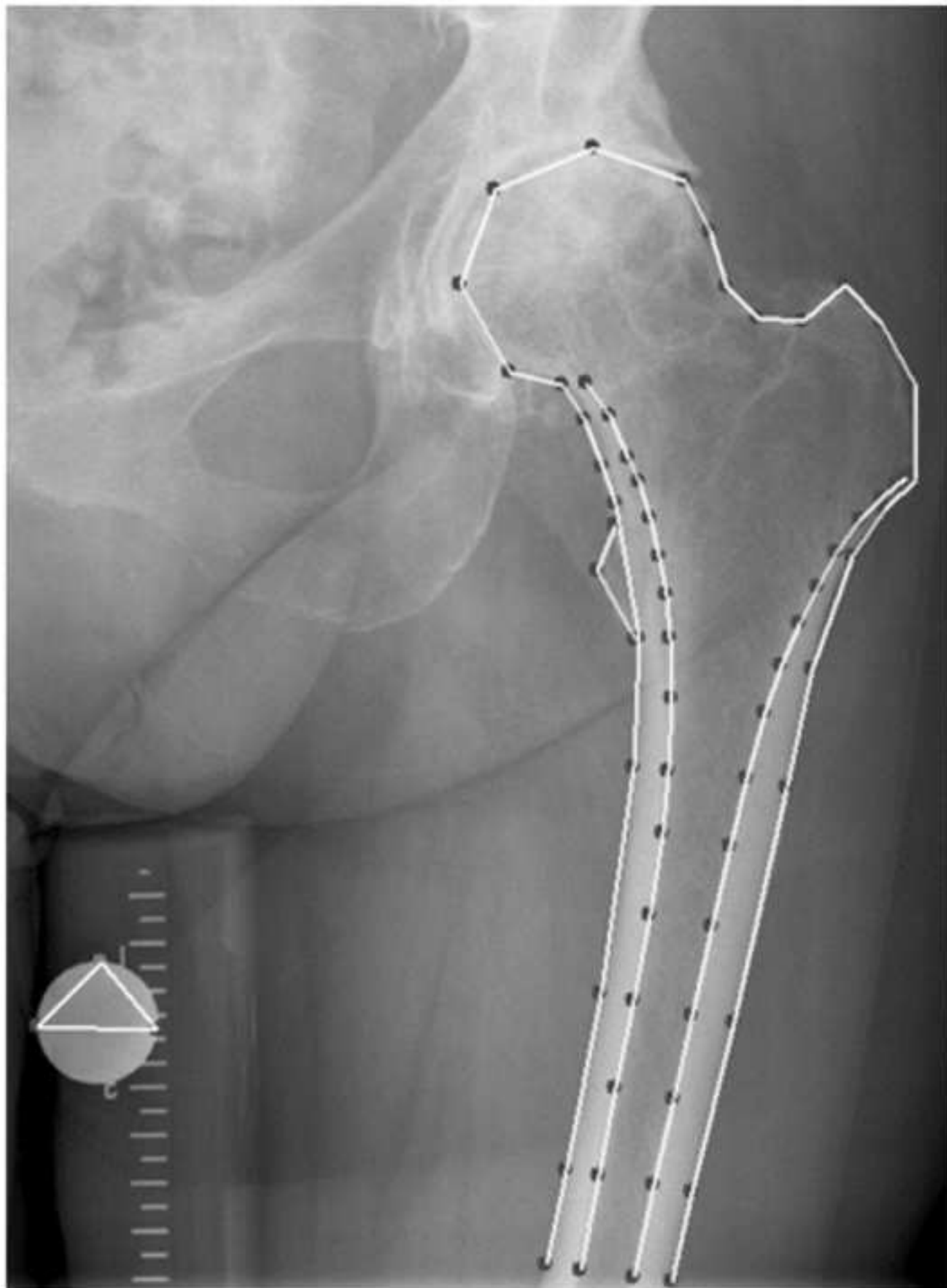


Figure 2
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Figure 3
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